Role Of The
Liquids From Coal Process
In The World Energy Picture

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ABSTRACT

ENCOAL Corporation, a wholly owned indirect subsidiary of Zeigler Coal Holding Company, has essentially completed the demonstration phase of a 1,000 Tons per day (TPD) Liquids From Coal (LFC™) plant near Gillette, Wyoming. The plant has been in operation for 4½ years and has delivered 15 unit trains of Process Derived Fuel (PDF™), the low-sulfur, high-Btu solid product to five major utilities. Recent test burns have indicated that PDF™ can offer the following benifits to utility customers:

- Lower sulfur emissions
- Lower NO_x emissions
- Lower utilized fuel costs to power plants
- Long term stable fuel supply

More than three million gallons of Coal Derived Liquid (CDL™) have also been delivered to seven industrial fuel users and one steel mill blast furnace. Additionally, laboratory characteristics of CDL™ and process development efforts have indicated that CDL™ can be readily upgraded into higher value chemical feedstocks and transportation fuels.

Commercialization of the LFC™ is also progressing. Permit work for a large scale commercial ENCOAL® plant in Wyoming is now underway and domestic and international commercialization activity is in progress by TEK-KOL, a general partnership between SGI International and a Zeigler subsidiary.

The Project[1], which was cost shared by the U.S. Department of Energy under Round Three of the Clean Coal Technology program, achieved its remaining long-term objectives in the past year. These included delivery and testing of pure PDF™ in a major Eastern U.S. bituminous coal

boiler, operation of the plant for long periods at greater than 90% availability and processing of an alternate source coal. Plans are to continue operation of the ENCOAL® plant for several purposes:

- testing the viability of alternate commercial scale equipment
- delivery of additional test burn quantities of products
- training operators for the commercial plant
- providing additional design data for the commercial plant

A no-cost extension to the Cooperative Agreement has been approved for six months to complete the required project close-out reports. This paper covers the historical background of the Project, describes the LFC™ process and describes the worldwide outlook for commercialization.

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[1] Contract No. DE-FC21-90MC27339, ENCOAL Corporation, P. O. Box 3038, Gillette, WY 82717; Telefax (307) 682-7938

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BACKGROUND INFORMATION

Objectives

Beneficiation of low sulfur Powder River Basin (PRB) subituminous coal is being demonstrated by the ENCOAL® Mild Coal Gasification Project using the LFC™ process. The LFC™ Technology employs a mild gasification process, that is mild pyrolysis at relatively low temperatures, to produce both liquid and solid fuels with environmentally superior properties. The demonstration plant has been in the testing and operations mode for more than 4½ years and has completed all of its original long-term goals.

ENCOAL's overall objective for the Project is to further the development of full sized commercial plants using the LFC™ Technology. In support of this overall objective, the following goals were established:

- Provide sufficient products for full-scale test burns
- Develop data for the design of future commercial plants
- Demonstrate plant and process performance
- Provide capital and operating cost data
- Support future LFC™ Technology licensing efforts

Significant progress has been made on the first four goals, and the commercialization and technology licensing efforts are in progress. This paper highlights several areas of immediate interest to potential customers and licensees. These include the status of the ENCOAL® Project, plant operating experience, plant reliability, product properties, technology development and remaining challenges. Most importantly, the status of the commercialization of the LFC™ Technology is reviewed.

General Description

ENCOAL® Corporation is a wholly owned subsidiary of Bluegrass Coal Development Company, (formerly named SMC Mining Company), which in turn is a subsidiary of Zeigler Coal Holding Company. ENCOAL® has entered into a Cooperative Agreement with the United States Department of Energy (DOE) as a participant in Round III of the Clean Coal Technology

Program. Under this agreement, the DOE has shared 50% of the cost of the ENCOAL® Mild Coal Gasification Project. The Cooperative Agreement was extended in October 1994 for an additional $18,100,000 bringing the Project total to $90,600,000 through September 17, 1996. A no-cost extension in September 1996 moved the Cooperative Agreement end date to March 17, 1997 to allow for completion of final reporting requirements. A license for the use of LFC™ Technology has been issued to ENCOAL® from the technology owner, TEK-KOL, a general partnership between SGI International of La Jolla, California and a subsidiary of Zeigler Coal Holding Company.

The ENCOAL® Project encompasses the design, construction and operation of a 1,000 TPD commercial demonstration plant and all required support facilities. The Project is located near Gillette, Wyoming at Triton Coal Company's Buckskin Mine. Existing roads, railroad, storage silos and coal handling facilities at the mine significantly reduced the need for new facilities for the Project.

A substantial amount of pilot plant testing of the LFC™ process and laboratory testing of PDF™ and CDL™ was done.[1] The pilot plant tests showed that the process was viable, predictable and controllable and could produce PDF™ and CDL™ to desired specifications. Key dates and activities in bringing the project from the pilot plant stage to its current status are:

- Through early 1987: Development of the LFC™ process by SGI.
- Mid 1987: SMC Mining Company (SMC) joined with SGI on further development.
- Mid 1988: Feasibility studies, preliminary design, economics and some detailed design work by SMC.
- June 1988: Submittal of an application to the State of Wyoming for a permit to construct the plant - Approved July 1989.
- August 1989: ENCOAL® Project submitted to the DOE as part of Round III of the Clean Coal Technology Program - Selected in December 1989.
- September 1990: Cooperative Agreement signed. Contract awarded to The M. W. Kellogg Company for engineering, procurement and construction.
- October 1990: Ground breaking at the Buckskin Mine site.
- April 1992: Mechanical completion - commissioning begun.
- June 1992: First 24 hour run in which PDF™ and CDL™ were produced.
- November 1992: SMC Mining Company and its subsidiaries, including ENCOAL®, acquired by Zeigler.
- April 1993: ENCOAL® achieves two week continuous run.
- June 1993: Plant shut down for major modifications.
- December 1993: Plant recommissioned with added deactivation loop.
- July 1994: Completed 68 day continuous run - plant operational.
- September 1994: First unit train containing PDF™ shipped and burned

successfully.

- October 1994: Two year extension and additional funding approved by DOE.
- April 1996: Shipped first unit train containing 100% PDF™.
- May 1996: Sucessfully burned PDF™ in a fully instrumented major U.S. utility boiler.

Although designed for 1000 TPD feed, the plant is currently processing 500 TPD of subituminous PRB coal due to capacity limitations in the deactivation loop. The plant produces 250 TPD of PDF™, which has the high heat content of Eastern coals but with low sulfur content, and 250 barrels/day of CDL™ , which is a low sulfur industrial fuel oil. While CDL™ is different from petroleum derived oils in its aromatic hydrocarbon, nitrogen and oxygen content, it has a low viscosity at operating temperatures and is comparable in flash point and heat content.

Not a pilot plant or a "throw-away", ENCOAL's processing plant is designed to commercial standards for a life of at least 10 years. It uses commercially available equipment as much as possible, state-of-the-art computer control systems, BACT for all environmental controls to minimize releases and a simplified flowsheet to make only two products matched to existing markets. The intent is to demonstrate the core process and not make the project overly complicated or expensive.

The ENCOAL® Project has demonstrated for the first time the integrated operation of several unique process steps:

- Coal drying on a rotary grate using convective heating
- Coal devolatilization on a rotary grate using convective heating
- Hot particulate removal with cyclones
- Integral solids cooling and deactivation
- Combustors operating on low Btu gas from internal streams
- Solids stabilization for storage and shipment
- Computer control and optimization of a mild coal gasification process
- Dust suppressant on PDF™ solids

Utility test burns have shown that the fuel products can be used economically in commercial boilers and furnaces to reduce sulfur emissions significantly at utility and industrial facilities currently burning high sulfur bituminous coal or fuel oils. Ultimately, installation of commercial scale LFC™ plants should help reduce U.S. dependence on imports of foreign oil.

Process Description

Figure 1 is a simplified flow diagram of ENCOAL's application of the LFC™ Technology. The process involves heating coal under carefully controlled conditions. Nominal 3" x 0" run-of-mine

(ROM) coal is conveyed from the existing Buckskin Mine to a storage silo. The coal from this silo is screened to remove oversize and undersize materials. The 2" x 1/8" sized coal is fed into a rotary grate dryer where it is heated by a hot gas stream. The residence time and temperature of the inlet gas have been selected to reduce the moisture content of the coal without initiating chemical changes. The solid bulk temperature is controlled so that no significant amounts of methane, carbon monoxide or carbon dioxide are released from the coal.

The solids from the dryer are then fed to the pyrolyzer where the temperature is further raised to about 1,000^{o}F on another rotary grate by a hot recycle gas stream. The rate of heating of the solids and their residence time are carefully controlled, because these parameters affect the properties of both solid and liquid products. During processing in the pyrolyzer, all remaining water is removed, and a chemical reaction occurs that results in the release of volatile gaseous material. Solids exiting the pyrolyzer are quickly quenched to stop the pyrolysis reaction, then transferred to a small surge bin that feeds the vibrating fluidized bed (VFB) deactivation unit.

In the VFB unit, the partially cooled, pyrolyzed solids contact a gas stream containing a controlled amount of oxygen. Termed "oxidative deactivation," a reaction occurs at active surface sites in the particles reducing the tendency for spontaneous ignition. The heat generated by this reaction is absorbed by a fluidizing gas stream which is circulated through a cyclone to remove entrained solids and a heat exchanger before being returned by a blower to the VFB. Oxygen content in the loop is maintained by introducing the proper amount of air through a control valve. Excess gas in the loop is purged to the dryer combustor for incineration.

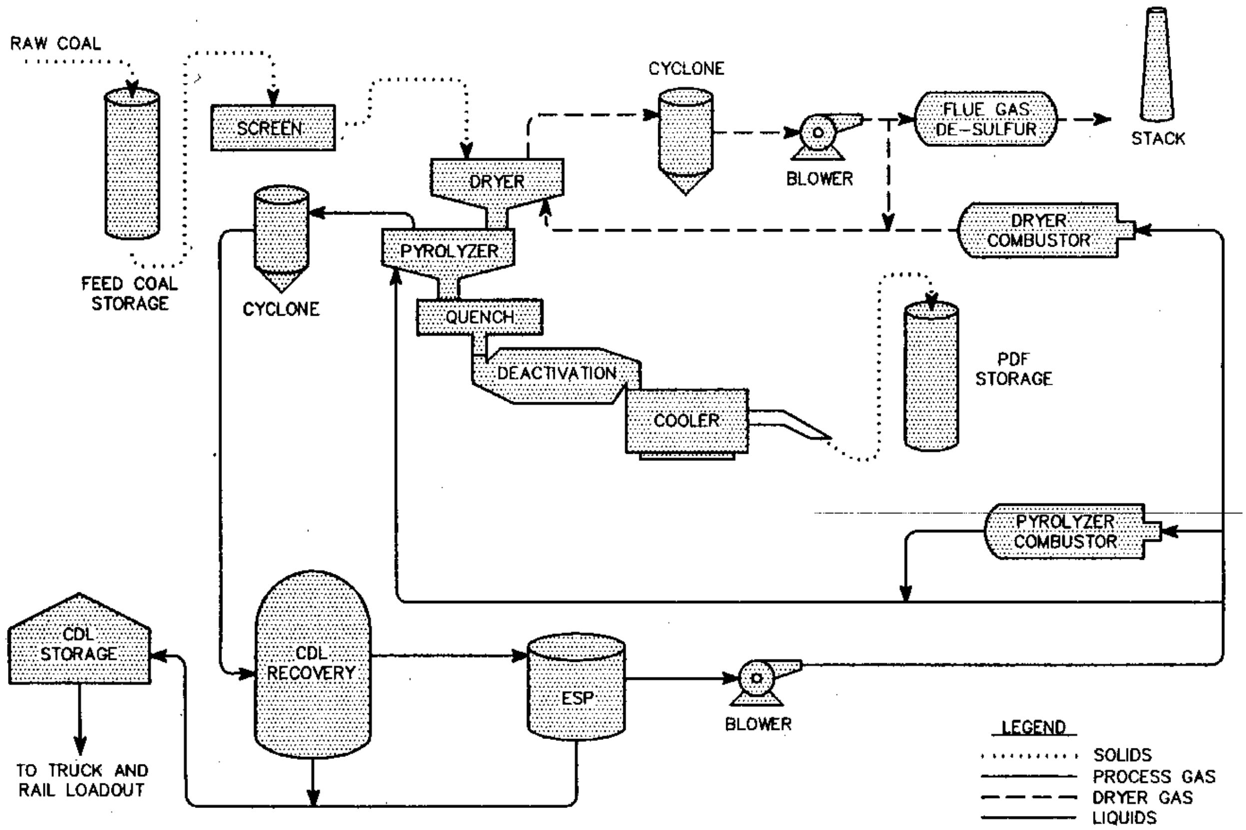

FIG. 1 : SIMPLIFIED PROCESS FLOW DIAGRAM

Following the VFB, the solids are cooled to near atmospheric temperature in an indirect rotary cooler. A controlled amount of water is added in the rotary cooler to rehydrate the PDF™ to near its ASTM equilibrium moisture content. This is also an important step in the stabilization of the PDF™. The cooled PDF™ is then transferred to a storage bin. Because the solids have little or no free surface moisture and, therefore, are likely to be dusty, a patented dust suppressant is added as PDF™ leaves the product surge bin. Patents are pending on both the oxidative deactivation andrehydration steps.

At the present time, the PDF™ is not completely stabilized with respect to oxygen and water upon leaving the plant. The PDF™ must be "finished" by a short exposure to atmospheric conditions in a layered stockpile prior to being reclaimed and shipped. In addition to atmospheric stabilized PDF™, a stable product can be made by blending run-of-plant PDF™ with either ROM coal or the atmosphere stabilized PDF™ , but there is a Btu penalty. ENCOAL® has recently completed pilot-scale equipment tests that successfully perform this finishing step using process equipment. The design uses commercially available equipment to be installed just downstream of rotary cooler mentioned above, and will effectively stabilize PDF™ on a continuous basis. Installation of this equipment is currently scheduled in 1997.

The hot gas produced in the pyrolyzer is sent through a cyclone for removal of the particulates and then cooled in a quench column to stop any additional pyrolysis reactions and to condense the desired liquids. Only the CDL™ is condensed in this step; the condensation of water is avoided. Electrostatic precipitators recover any remaining liquid droplets and mists from the gas leaving the condensation unit.

Almost half of the residual gas from the liquid recovery unit is recycled directly to the pyrolyzer, while some is first burned in the pyrolyzer combustor before being blended with the recycled gas to provide heat for the mild gasification reaction. The remaining gas is burned in the dryer combustor, which converts sulfur compounds to sulfur oxides. Nitrogen oxide emissions are controlled via appropriate design of the combustor. The hot flue gas from the dryer combustor is blended with the recycled gas from the dryer to provide the heat and gas flow necessary for drying.

The unrecycled portion of the off-gas from the dryer is treated in a wet gas scrubber and a horizontal scrubber, both using a water-based sodium carbonate solution. The wet gas scrubber recovers the fine particulates that escape the dryer cyclone, and the horizontal scrubber removes most of the sulfur oxides from the flue gas. The treated gas is vented to a stack. The spent solution is discharged into a pond for evaporation. The plant has several utility systems supporting its operation. These include nitrogen, steam, natural gas, compressed air, bulk sodium carbonate and a glycol/water heating and cooling system. Figure 2 is a plot plan for the ENCOAL® Plant facilities including the Buckskin Mine rail loop that is used for shipping products.

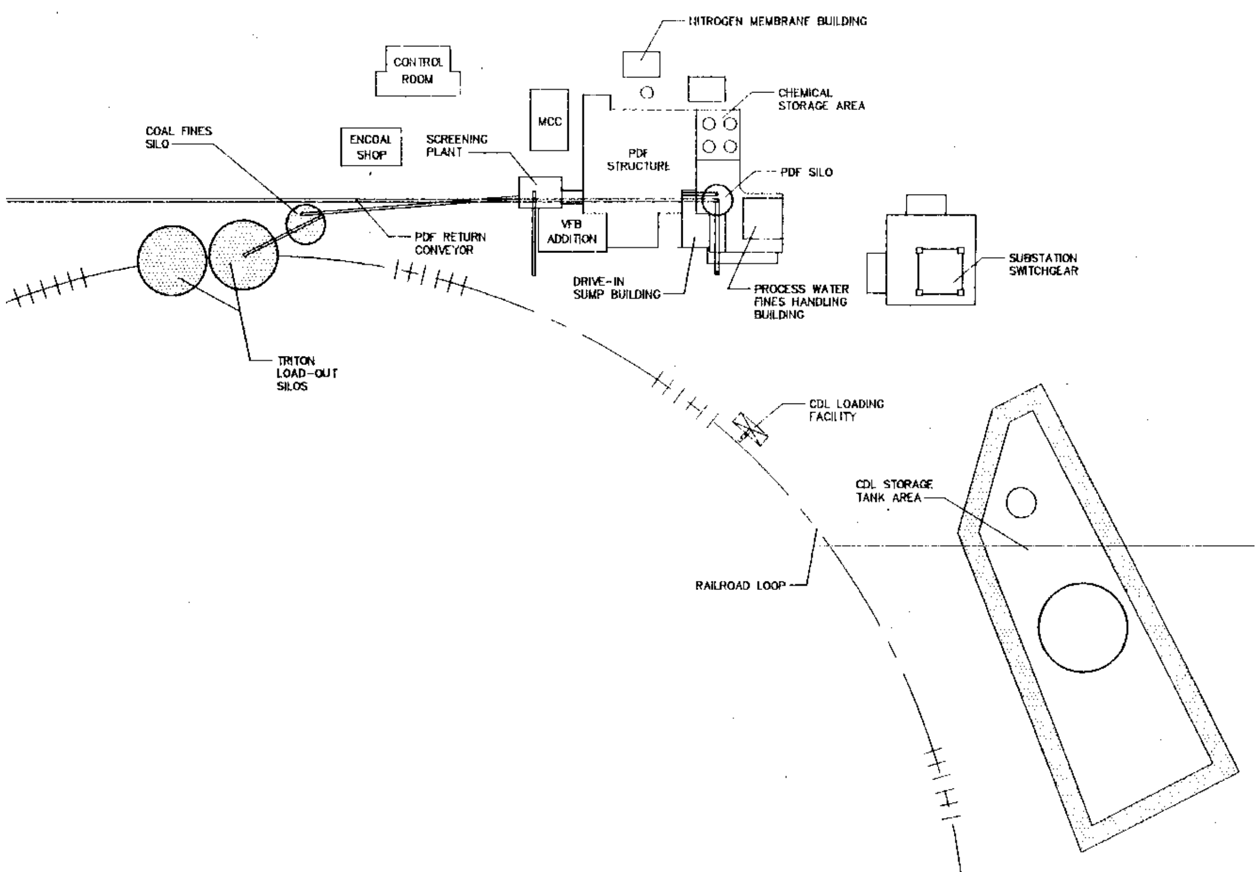

FIG. 2 : ENCOAL PROJECT PLOT PLAN

PLANT OPERATING EXPERIENCE

Production History

ENCOAL's LFC™ plant and facilities have now operated in an integrated mode producing PDF™ and CDL™ for more than 12,000 hours. The major pieces of equipment, including the large blowers, combustors, dryers, pyrolyzer and cooler have operated fare more hours overall considering hot standby and ramping operations. This equipment has been demonstrated to operate reliably. Steady state operation exceeding 90% availability has been achieved for extended periods for the entire plant, albeit at 50% of plant capacity, and the plant is currently operational. Although some testing is still ongoing, all of the plant production of PDF™ and CDL™ is for test burns. Table1 summarizes the plant operations over the last 4½ years.

	1992	1993	1994	1995	1996*
Raw Coal Feed (Tons)	5,200	12,400	67,500	65,800	59,500
PDF™ Produced (Tons)	2,200	4,900	31,700	28,600	30,500
PDF™ Sold (Tons)	-0-	-0-	23,700	19,100	32,700
CDL™ Produced (Bbl)	2,600	6,600	28,000	31,700	27,500
Hours on Line	314	980	4,300	3,400	3,200
Average Length of Runs	2.2	8.2	25.9	38.0	N/A**

***	Through November 15, 1996**
****	Not Applicable; Plant in operation.**

Table 1. ENCOAL® Plant Performance

Product recoveries from the feed coal have varied somewhat from the original projections. In the case of PDF™, recovery has been slightly lower. This is because more fines are generated in the process than expected and they are not all currently recovered. CDL™ recovery is higher than expected by 10-15%, apparently due to a more efficient liquid recovery system than the one used in the pilot plant.

Product Test Burns

Commercialization of both the solid (PDF™) and liquid (CDL™) products from the ENCOAL® Plant took a major step forward in 1994. PDF™ was shipped in trainload quantities for the first time to utility customers. The results of these shipments demonstrated that utility and industrial users can plan for test burns of PDF™ with confidence. Use of CDL™ in the industrial low sulfur residual fuel oil market was also demonstrated.

In September 1994, ENCOAL® commenced shipment of PDF™ to utility customers via the Burlington Northern railroad. Shipments made to the first customer, the Western Farmers Electric Cooperative in Hugo, Oklahoma, started at a 15% blend level and ranged up to 30%. The upper level of these blends was determined by the heat content limit in the customer's boiler. Shipments to a second customer, Muscatine Power and Water in Muscatine, Iowa, started at 40% PDF™ and ranged up to 91%. The rail cars in this shipment were capped with a small amount of ROM Buckskin coal. Capping is one way to control loss of fine material during shipment. Because the ROM coal becomes blended with the PDF™ upon unloading, it ends up as a 91% blend.

With these first shipments, ENCOAL's goals were to demonstrate its ability to coordinate with the Buckskin Mine in loading and shipping consistent blends, to ship PDF™ with dust generation comparable to or less than ROM Buckskin coal, and to ship PDF™ blends that are stable with respect to self heating. Furthermore, ENCOAL® intended to demonstrate that PDF™ could be transported and delivered to customers using regular commercial equipment. With respect to utilization, the goal for these shipments was for customers to burn trial amounts (½ unit train minimum) of PDF™ blends with minimal adjustment of equipment. These goals have all been met as reported in a more detailed test burn report[2].

In 1995, ENCOAL® shipped two additional trains to Muscatine and initiated shipments to a third customer, Omaha Public Power District (OPPD) in Omaha, Nebraska. Three unit trains were shipped to OPPD containing approximately 25% PDF™ . This customer has been burning PRB coal in a boiler designed for bituminous coal for some time, and the increased heat content of the PDF™ blends helped increase plant output.

In 1996, ENCOAL® began shipping unit trains containing 100% PDF™ for the first time. As of the end of October 1996, two 100% PDF™ unit trains have been delivered to two separate utilities for test burns. The first was burned in Indiana-Kentucky Electric Cooperative's (IKEC) Clifty Creek Station, which is jointly owned by American Electric Power (AEP). The PDF™ was blended with Ohio high sulfur coal at the utility and burned in the Babcock & Wilcox open-path, slag-tap boiler with full instrumentation. Blends tested ranged between 70 and 90% PDF™, and burn results indicated that even with one pulverizer out of service, the unit capacity was increased significantly relative to the base blend. More importantly, there was at least a 20% NO_x reduction due to a more stable flame. Completion of this test burn achieved a major DOE Cooperative Agreement Milestone of testing PDF™ at a major U.S. utility. This goal is discussed further in an independent third party test burn report.[6] The remaining 100% PDF™ unit train was sent to Union Electric near St. Louis, MO. PDF™ shipments through October 1996 are documented in

Table 2.

Coincident with PDF™ shipments was a broadening of the customer base for the liquid CDL™ product. To date, ENCOAL® has shipped CDL™ to eight different customers. With the exception of one steel mill injectant test, the CDL™ has been blended and used as fuel oil. CDL™ has proven to be acceptable in the fuel oil market through these test burns.[2] However, since the price of fuel oil is currently very low, upgrading of CDL™ into more profitable products has been studied. Initial testing of CDL™ has shown that extraction of higher value products is both technically and economically feasible. Detailed characterization of the CDL™ and evaluation of several upgrading processes have already been completed. Other processes continue to be studied, but in general, upgrading of CDL™ will yield specialty chemical feedstocks and transportation fuels. Further work on upgrading is planned in 1997. Table 3 summarizes the CDL™ tank car shipments thus far.

DATE LOADED	CUSTOMER	BLEND (%PDF™)	TONS SHIPPED			HEAT CONTENT (Btu/lb)
			PDF™	COAL	BLEND	
09/17/94	W. Farmers	14.4	922	5,448	6,370	8,760
09/24/94	W. Farmers	21.2	1,080	4,020	5,100	8,910
10/01/94	W. Farmers	25.1	1,508	4,493	6,001	8,940
10/10/94	W. Farmers	31.9	1,603	3,241	5,024	9,310
10/24/94	W. Farmers	24.0	2,665	8,426	11,091	9,060
11/23/94	Muscatine	39.0	1,957	3,122	5,079	9,630
11/29/94	Muscatine	66.6	3,423	1,713	5,136	9,670
12/13/94	Muscatine	90.7	10,576	1,082	11,658	10,000
04/23/95	Muscatine	33.0	3,979	8,094	12,073	9,127
05/05/95	Omaha PPD	24.4	2,711	8,412	11,123	8,940
05/11/95	Omaha PPD	24.0	2,669	8,464	11,133	8,939
05/13/95	Omaha PPD	26.0	2,952	8,398	11,350	8,854
08/16/95	Muscatine	94.0	6,750	434	7,184	9,873
04/25/96	IKEC (AEP)	100.0	9,739	0	9,739	10,682
07/22/96	Union Electric	100.0	11,260	0	11,260	10,450

Table 2. Summary of Trains Shipped Containing PDF™ *(Through 10/31/96)*

CUSTOMER	# OF CARS	DESTINATION	USE
Dakota Gas	87	Beulah, ND	Industrial Boiler
Texpar	3	Milwaukee, WI	Small Boilers
3 M Company	14	Hutchinson, MN	Industrial Boiler
Kiesel	2	St. Louis, MO	Blend W/ #6 Oil
US Steel	2	Chicago, IL	Steel Mill Blast Furnace
Michigan Marine	18	Detroit, MI	Blend W/ #6 Oil
M&S Petroleum	40	Lake Charles, LA	Fuel Oil Blend
Baka Energy INC.	6	Houston, TX	Fuel Oil Blend

Table 3. Summary Of CDL™ Tank Car Shipments ***(Through 11/15/96)***

CHALLENGES

A detailed review of equipment and plant modifications through July 1995 has been presented[1,3,5]. Table 4 summarizes the major challenges that have been overcome and the solutions implemented.

AREA OF PLANT	DEFINITION OF PROBLEM	SOLUTION
Electrostatic Precipitators	Insulator Failures	Modified Insulators, Improved Temperature Control
Material Handling	Plugging and Spillage	Modified S-belts & Chutes
PDF™ Quenching and Steam Condenser	Oil and Coal Dust, Too Small	Added Scrubber, Added 2 Larger Exchangers
Dryer and Pyrolyzer	Sand Seal Failures	Replaced With Water Seals
Combustors	Unstable Operation	Revised Control System
Pumps and Blowers	Sizing Problems, Mostly Too Small	Replaced With Larger Equipment
Changing Process Variables	Initial Plant Design Parameters Were Off	Adjusted Operating Set Points
PDF™ Dust Collection	Dusty Conditions On Product Side of Plant - No Scrubbers	Added Two Wet Scrubbers
PDF™ Deactivation	Could Not Produce Stable PDF™ In Original Equipment	Added VFB Deactivation Loop Equipment
Process Water System	Accumulation Of Oily Fines In Process Equipment	Installed Clarifier, Floc & Vacuum Filter
Cyclone Fines Handling	Loss Of Excessive Amounts Of PDF™ In Cyclone Fines, Labor Intensive Clean-up	Recovered VFB Deactivation Fines Into PDF™ Product, Reduced Handling System
VFB Drag Conveyors	Excessive Wear and Maintenance Intensive	Redesigned High Wear Points, Modified Discharges To Reduce Plugging
Plant Operability And Maintenance	Difficult Access, Labor Intensive Clean-up, Inflexible To Operate	Piping Revisions, Access Platforms And Doors, Relocate Valves

Table 4. Summary Of Plant Modifications

Still to be solved are several challenges involving plant capacity, PDF™ deactivation, and removal of coal fines from the CDL™. In addition, CDL™ upgrading even on the small scale of the ENCOAL® plant, appears to be economically attractive as well as something that needs to be tested before application in a large commercial plant. Data collection and designs are complete for the plant capacity improvements and PDF™ finishing projects, and work on the other projects scheduled for next year is in progress.

PDF™ Deactivation

Total product deactivation remains a key challenge. At the present time, the PDF™ is not completely stabilized in the plant but has to be "finished" by a short exposure to atmospheric conditions external to the plant. ENCOAL® has recently completed pilot-scale equipment tests that successfully performed this finishing step using process equipment. The design uses commercially available equipment to be installed just downstream of the rotary cooler, and will effectively stabilize PDF™ on a continuous basis. Installation of this equipment is currently scheduled in 1997.

Plant Capacity

One known bottleneck remains that prevents attainment of full design capacity of 1,000 TPD. The VFB loop is the limiting factor, since it was designed for 50% of plant capacity. A second unit was planned once the effectiveness of the PDF™ deactivation process was demonstrated. After the PDF™ finishing equipment mentioned above is installed, the addition of the second VFB may be required to reach full plant capacity.

CDL™ Upgrading

The ENCOAL® plant was intentionally designed to capture a single, wide-boiling-range liquid product, CDL™ , as opposed to making multiple liquid fractions. This was done to simplify the operation, lower the capital cost and reduce the risk associated with the added complication of liquid separations. It was determined that this would be evaluated after the basic LFC™ Technology had been demonstrated. Attention has now been turned to CDL™ upgrading since the plant has moved into a production mode.

Some preliminary feasibility and design work has indicated that upgrading of the CDL™ both in the ENCOAL® plant and on a commercial scale makes economic sense; indeed it may be required to produce products that can be sold in quantity in existing markets. The M. W. Kellogg Company developed a design and cost estimate for modifying the existing plant for upgrading CDL™ in 1995. The design used information from laboratory studies and a complete CDL™ chemical characterization to develop the a workable process.

The basic concept is to produce three commercially viable streams; (1) a transportation grade fuel feedstock that would include most of the aliphatic compounds present in CDL™, (2) a tar acid fraction that would include the cresylic acids, phenols and light aromatics and (3) a heavy residual bottom that would be suitable as anode binder pitch. This concept is currently being considered for implementation in the ENCOAL® plant to demonstrate its potential for commercial- sized LFC™ plants as well as to enhance the economics of continued operation of the existing plant.

CDL™ Solids Removal

The pyrolyzer loop cyclone was specifically designed to remove the coal fines from the gas stream prior to recovery of the CDL™ in the quench tower and ESP's. However, the cyclone does not effectively remove all of the fines, and the CDL™ consequently has 2 to 4% entrained solids. All CDL™ upgrading schemes identified to date have indicated that the fines in the CDL™ are undesirable. The fines must therefore be removed or reduced in quantity in order to meet customer requirements for any sale other than fuel oil. Testing of various methods of solid/liquid separation techniques is ongoing, and installation of a system at the ENCOAL® plant is scheduled in 1997.

PDF™ Properties

After 4½ years of operation and production of 97,900 tons of PDF™, the properties of PDF™ that can be produced in the plant are fairly well defined. The variables that are controllable to some extent in the process are the heat content, volatiles, and moisture. The components dictated by the composition of the feed coal are ash, sulfur, size consist, and hardness. The LFC™ process has little impact on the ash composition or ash fusion temperature. Test data have been presented in previous reports[3] that show the variability of the PDF™ with process conditions. Table 5 represents the averages of the PDF™ that are currently being made at the ENCOAL® plant.

PROXIMATE ANALYSIS	PLANT RUN	LAYDOWN BLEND	TARGET
Heat Content (Btu/lb)	11,112	10,682	11,400 - 11,600
Moisture (%)	9.81	10.1	8 - 9
Ash (%)	7.56	7.9	6 - 9
Volatile Matter	25.93	26.7	21 - 24
Fixed Carbon (%)	56.70	54.8	57 - 60
Sulfur (%)	0.41	0.52	0.51 Maximum
OTHER			
Hardgrove Grindability	47	43	45 - 50
#Sulfur/MMBtu	0.37	0.40	0.45 Maximum
#SO_2/MMBtu	0.74	0.81	0.90 Maximum
Ash Mineral Analysis	Same as coal	Same as coal	Same as coal
Ash Fusion Temperature	2220°F	2220°F	2220°F

Table 5. Average Representative Properties of PDF™

CDL™ Properties

Like PDF™, the properties of CDL™ are influenced by the pyrolyzer operation. However, the properties of CDL™ are also influenced by operation of equipment in the pyrolysis gas loop, including the pyrolyzer cyclone, the quench tower and the electrostatic precipitators. These directly affect the amount of water and sediment in the CDL™. Again, a significant amount of data has been presented in previous reports[3], so only the following summary table is presented here. A significant amount of work has been done on the detailed chemical characterization of CDL™ for the upgrading project discussed above. This work is ongoing and will be the subject of future reports.

	CDL™	Low Sulfur Fuel Oil
API Gravity (°)	1.3 - 3.2	5
Sulfur (%)	0.3 - 0.5	0.8
Nitrogen (%)	0.6	0.3
Oxygen (%)	6.2	0.6
Viscosity @ 122°F (cs)	280	420
Pour Point (°F)	66 - 90	50
Flash Point (°F)	165	150
MBtu/gal	140	150
Water (wt %)	0.5	<1
Solids (wt %)	2 - 4	<1
Ash (wt %)	0.2 - 0.4	<1

Table 6. Average CDL™ Quality

COMMERCIALIZATION

ENCOAL® Corporation has a sublicense for the LFC™ Technology from the TEK-KOL Partnership. The Partnership, owned by SGI International and a subsidiary of Zeigler Coal Holding Company, is responsible for the commercialization and licensing of the LFC™ Technology and thus is carrying out ENCOAL's obligation under the Cooperative Agreement. Under the TEK-KOL Partnership Agreement, SGI International is designated as the Licensing Contractor responsible for licensing and promoting the LFC™ Technology. Zeigler is the administrative partner responsible for preparation of lease agreements and contracts.

Commercialization of the LFC™ Technology consists of marketing the products, PDF™ and CDL™, to interested consumers at prices that will support the construction of commercial plants. Concurrently, the LFC™ Technology must be licensed to the prospective plant owners. These may or may not be the same as the consumers of the products. The technology and product marketing activities are closely interwoven and are carried out by both TEK-KOL partners. For the most part, ENCOAL® carries out allZeigler partnership activities.

In order to determine the viability of potential LFC™ plants, TEK-KOL has already completed several detailed commercial plant feasibility studies (called Phase II studies as described previously [3]). These studies include plant design, layout, capital estimates, market assessment for co-products, operating cost assessments, and overall financial evaluation. Operation of the

ENCOAL® plant provided the basis for estimating operating cost and commencing product market development, and unlike most upgrading projects, full-scale shipment and test burns made possible by the near-commercial size of the ENCOAL® plant has provided actual market information for the basis of these studies. Operating experience of the ENCOAL® facility was also used for the design basis and capital estimates. In February 1996, TEK-KOL and Mitsubishi Heavy Industries (MHI) signed an agreement to jointly produce Design and Engineering Cost Estimates for commercial LFC™ plants. This arrangement combines the scientific, engineering, and operating experience of the TEK-KOL staff with the engineering and design experience of MHI to produce a comprehensive study. To date, three detailed LFC™ Phase II studies have been completed by the TEK-KOL/MHI team. These studies are discussed below.

Domestic Markets

The most promising markets for the application of the LFC™ Technology in the U.S. are the subituminous coal deposits in the Powder River Basin. Close behind are the subituminous reserves in Alaska's Beluga field, lignites in North Dakota, followed by Texas lignites near San Antonio. Testing on all of these coals has been conducted in the TEK-KOL Development Center (Center) Sample Production Unit (SPU) with favorable results.

Application of the LFC™ Technology to swelling or agglomerating coals is not feasible at this time, so most of the central and eastern U.S. coals are not candidates. Removal of sulfur by the LFC™ process has proven to be significant, especially when the sulfur form is highly organic, but these bituminous coals would still be too high in sulfur after processing to meet the amended clean air act requirements. Central and eastern U.S. coals are also more costly to mine than western subituminous coal, leaving less margin for upgrading. For these reasons, central and eastern U.S. coals do not appear to be promising candidates for LFC™ processing.

Powder River Basin. A large portion of the extensive U.S. coal reserves lie in the Powder River Basin in Montana and Wyoming. Subituminous and low in sulfur, this coal is ideal for processing via the LFC™ Technology. That is a major reason the ENCOAL® plant was located near Gillette. The southern end of the PRB in Wyoming is of special interest because the sulfur and ash are especially low. Here the PDF™ product may have an increased value for metallurgical applications or as a super compliance blending material.

Overall, the PRB has the lowest mining costs in the U.S. and, being a long distance from the major utility markets, has the highest transportation costs. This combination yields a large differential value between the raw material cost and the delivered cost. The high incremental value, a well developed transportation infrastructure, qualified, available labor force and a large number of operating mines mean that the opportunities for installation of commercial LFC™ plants are very good for the PRB.

A Phase II technical and economic feasibility study was completed on one potential PRB site in 1996. This study was for a commercial-size LFC™ plant to be located at Triton Coal Company's North Rochelle Mine site. The site includes three 5,500 ton feed coal/day LFC™ modules, a 240

MW cogeneration plant, and CDL™ upgrading facilities integrated with the mine-site infrastructure. Results of the study indicated that the project has a financible rate of return *(>15%)* without any government subsidies, price supports, or tax credits. In other words, the LFC™ products compete in current markets at current prices. However, the aid of government tax incentives would help off-set the financial risk associated with a project of this magnitude. This study was recently refined in order to confirm the project economics, and to assemble design information for submittal of permit applications required by the State of Wyoming to allow construction to begin. An air permit application was submitted in November 1996 followed by Land Quality and Industrial Siting Permits around the end of the year.

Alaska. There are two promising areas in Alaska for the installation of commercial LFC™ plants, namely the Beluga fields and the Healy deposits. Both areas have extensive reserves, are largely subituminous in nature and have low ash and sulfur. The Beluga coal is very near the Cook Inlet with the possibility of a deep water port for exports. However there is essentially no infrastructure to produce these reserves and this would be a costly venture. Current owners of the three main lease areas have not been able to attract buyers of the coal in the current market. Mine development would have to be included in any LFC™ plant venture.

At Healy, there is an existing producing mine and coal is shipped by rail to the coast for export. The Healy coal has been tested at the Center with good results. However the cost of mining is fairly high, transportation costs are high and there is no local market. The PDF™ and CDL™ from a project in this area may have difficulty competing with other locations.

North Dakota Lignite. Significant reserves of lignites are present in the Williston Basin of North Dakota and tests on some of them indicate good potential for LFC™ processing. Lab tests have indicated that good quality PDF™ and acceptable yields of CDL™ are produced using LFC™ Technology. Most recently, these coals have been further tested at the Center for mechanical strength during processing, also with positive results.

Overall, the economics of commercial LFC™ plants for the North Dakota lignites appear attractive. The coal seams are relatively thick and the sulfur and ash content are low, although not as low as the PRB. However, North Dakota is closer to some important markets. This coal is being considered for an alternate coal test in the ENCOAL® plant.

Texas Lignite. Numerous tests on Texas lignites have been conducted at the Center. With some lignites, the PDF™ quality and CDL™ recoveries have proven to be acceptable. However, other Texas lignites, although extensively available, are not considered to be viable candidates because of poor coal quality. Coal quality combined with proximity of the existing lignite mines near power plants designed to burn ROM material, makes the application of an LFC™ plant unlikely in the near future. Interest in exporting upgraded Texas lignites into other markets, or applying an LFC™ facility to replace an existing coal drying process would be two most likely scenarios for a Texas based facility.

International Markets

TEK-KOL is also actively pursuing international opportunities for applying the LFC™ Technology. Primary areas of immediate interest are in China, Indonesia, and Russia. These areas have been identified by TEK-KOL as the most likely to develop in the near future, and accomplishments in these areas are discussed in more detail below. Other potential international applications for the LFC™ Technology *(such as the Pacific Rim, Southeast Asia, India and Pakistan, Eastern Europe, and Australia)* that have previously been discussed[5], have been identified by TEK-KOL as longer range development projects. For this reason, progress in these areas is not discussed in this paper.

China. China is the largest producer as well as the largest consumer of coal in the world. Over a third of the coal production occurs in the three northern provinces of Shanxi, Shaanxi and Inner Mongolia. However, due to significant transportation infrastructure problems, it is not always possible to move the coal within China to meet local needs. As a result of the extremely high economic growth in the southern and eastern coastal regions of China accompanied by a parallel demand for new electrical power, there are predictions that China may require imports of coal in the range of 10-50 million tons per year by 2010. Furthermore, the predictable result of burning such prodigious quantities of coal, much of it high in sulfur, is an environmental problem of such magnitude that it is a major concern not only of the Chinese government but also for the governments of neighboring countries and, indeed, the world.

For these reasons, China is viewed as one of the prime candidates for application of the LFC™ Technology. The LFC™ Technology offers China the opportunity:

- to more efficiently and effectively employ its vast resources of coal
- to conserve scarce and valuable railroad assets as a result of the moisture reduction aspect of the LFC™ Technology
- to vastly expand its exports into the world steam coal and metalurgical markets and, thereby, generate much needed foreign revenue
- to augment valuable and increasingly scarce petroleum assets through the production of CDL™
- to reduce the extremely severe pollution problems associated with burning high sulfur coal

The LFC™ Technology has been actively promoted in China for several years with the Ministry of Coal Industry (MOCI) and officials of regional coal mine administrations by explaining the value of employing the LFC™ Technology and developing potential commercial plant projects. Although China has huge quantities of bituminous and anthracite coal, it also has great reserves of subituminous and lignite coals that are ideal candidates for upgrading using the LFC™ Technology. MOCI expressed keen interest in the advantage to China offered by the LFC™ Technology and representatives of SGI International have visited various mining areas in China that could be potential sites for LFC™ projects.

Indonesia. Approximately 93% of Indonesia's reported 36+ billion metric tons of reserves are in the form of subituminous and lignite coal. Significantly, though, this accounts for over 97% of the identified recoverable reserves in all of the Asian countries. These reserves are split approximately 70% on the island of Sumatra and 30% on the island of Kalimantan. In fact, the Indonesian reserves have not been definitively studied yet and there exists some question as to the full extent of the identified and hypothetical reserves. On a positive note, the vast majority of the mines are open-cut operations enjoying thick seams and are mostly located near the coast or close to a navigable river, facilitating ready access to international as well as domestic markets.

Indonesia's rapid economic growth during the past decade has fueled an increase in the demand for electrical power that has grown at 11-15% per year. Furthermore, although Indonesia has been a major exporter of oil, as a result of the surging domestic growth and the limited oil reserves, it is predicted to become a net importer of petroleum by the year 2000. While a significant portion of the coal production will be destined to feed the growing domestic electrical power and industrial needs, Indonesia also requires the foreign exchange credits which will result from increasing the export market. Consequently, it is under strong pressure to better exploit its vast reserves ofsubituminous and lignite coal.

Toward this end, work has been ongoing in Indonesia for over five years to promote the advantages of the LFC™ Process in answering many of Indonesia's needs. The coal industry is dominated by P.T. Tambang Batubara Bukit Asam (PTBA), the state coal mining corporation which operates under the Ministry of Mines and Energy. The structure of the industry includes the state-owned mines operated by PTBA, national companies contracted by PTBA under coal concession contract agreements, private domestic companies operating under mining concessions issued by PTBA and a few local area coal cooperatives.

Employment of the LFC™ process to upgrade low-rank coal would permit Indonesia, which is closer to Japan, South Korea, Taiwan and Hong Kong, to become very competitive in the steam coal markets. A Phase I study on some thirteen different samples indicated that several of the coals of the Tanjung Enim region of South Sumatra were good-to-excellent candidates for upgrading using the LFC™ process. Indonesia, which is short on invesment capital, submitted a request to the U.S. Trade and Development Agency (TDA) for a grant for a Phase II study. This grant was approved by the TDA, and a Phase II study was completed in September 1996. This project included one to three LFC™ modules with a range of 40 to 100 MW of cogeneration, along with CDL™ upgrading facilities, transportation infrastructure, and living quarters. The study did not include the development and operation of the adjacent mine. Economics of the PTBA study were encouraging, and efforts to sign a contract with PTBA to conduct a more detailed investigation are underway.

Additionally, one Phase II study on a site adjacent to a P.T. Berau Lati Mine in East Kalimantan was completed. The study included a single LFC™ module, 40MW cogeneration plant, and a CDL™ upgrading facility that was located adjacent to the existing mine river shipping station. This one module LFC™ plant case resulted in moderate economics due to its limited throughput and relatively high operating cost. The Lati Mine coal was determined to be exceptional candidate for upgrading using the LFC™ Technology. However, local infrastructure issues, including the price of feed coal, must be resolved before the situation becomes favorable for a profitable development of a commercial LFC™ project.

Opportunities continue to be pursued in Indonesia from Aceh at the northern tip of Sumatra to lignite mines in Sulawesi. The value of the LFC™ Technology to Indonesia parallels very closely the advantages mentioned for China. Where China enjoys huge production capabilities in all forms of coal, it is especially important to Indonesia to upgrade the vast reserves of subituminous and lignite coals in order to participate effectively in the world steam coal market. Much of Indonesian coal is already naturally low in sulfur, so the resulting PDF™ is particularly attractive to markets in Japan. Work is continuing with MHI and other Japanese firms interested in cooperating in the development of projects in Indonesia and the rest of Asia.

Russia. Russia accounts for about 60% of the coal production of the former Soviet Union with almost all the rest coming from Ukraine and Kazakhstan. The increasing importance of coal to the fuel and energy balance of Russia must be viewed with the understanding of the major drop in crude oil production and decreased growth rate of gas production. Representatives of the Russian coal group ROSUGOL and the Kemerovo Coal Certification Center in south central Siberia have been evaluating a project using the LFC™ Technology in the Kemerovo region. Following a visit to SGI's offices in La Jolla, California and the ENCOAL® Plant in Gillette, Wyoming, Russian representatives signed a letter of intent to proceed with Phase I and Phase II studies for an LFC™ project. The Russian delegation was particularly excited about the value added by the production of CDL™ which is so important in view of reduced oil production. The Phase I study was completed in late 1995, and indicated that the coals tested were suitable for LFC™ upgrading. Work on a Phase II study is expected to begin in 1997 pending Russian agreement to proceed. If successful, this Russian endeavor could be the first of many projects in this country with huge potential reserves.

Long Term Impact Of LFC™ Commercialization

The LFC™ Technology is uniquely positioned in the world coal conversion and upgrading market to impact two widely used fossil energy forms, namely solids and liquids. Many technologies have successfully demonstrated the conversion of coal to synthetic gases which are in turn used as a clean energy source. Others have demonstrated the manufacture of hydrocarbon liquids from these synthetic gases to serve as chemical or transportation fuel feedstocks. Still other technologies have demonstrated the technical feasibility of direct conversion of coal to hydrocarbon liquids. Although not truly coal conversion, coal upgrading by removal of undesirable constituents like water, sulfur and ash has also been extensively demonstrated on a commercial scale by numerous technologies. The LFC™ Technology alone produces both an upgraded solid product and hydrocarbon liquids.

Economic conditions for typical commercial coal conversion and upgrading projects are generally absent without some form of political intervention, such as price supports, grants, subsidies or artificial market constraints. While tax credits would be helpful on the first LFC™ plant to offset risks, commercial LFC™ plants can compete in today’s markets at today’s prices with attractive rates of return. Therefore, countries with significant indigenous coal reserves (like the U.S.) or countries with significant investment or material supply interests (like Japan), should be able to use the LFC™ Technology to further economic growth.

Of course there are practical limits to the application of the LFC™ Technology. Some of the criteria for successful commercial projects can be generally stated as:

- Significant coal reserves - greater than 150 million ton block for a 3 module LFC™ plant
- Non caking, non agglomerating coal - like most low rank coals
- Low mining costs
- Low ash and inorganic sulfur content
- Located near navigable water or other reasonably priced accessible form of transportation
- Favorable political climate
- Markets for products for products at acceptable prices

There are many coal deposits in the world today which meet all of these criteria.

Consumers of solid and liquid energy products, which more and more is a world-wide market, should see significant advantages in the products from commercial LFC™ plants. The benefits for the consumer can be summarized as:

- Reduced dependance on petroleum based liquid products and the widely variable prices in that market
- Reduced environmental impact from the burning of PDF™ and CDL™ in the form of lower SO_x and NO_x as demonstrated by test burns. LFC™ plants are also very environmentally benign
- Lower fuel costs for power plants and industrial boilers on a fully utilized basis
- Long term, stable fuel supply
- Unique characteristics for metallurgical and ferroally markets
- For consumers with coal reserves, incresed use of domestic resources

Given the widespread availability of qualified candidate coals and the numerous benefits that accrue to consumers of the LFC™ products, commercialization of the LFC™ Technology should be able to make a major long term positive impact on the world energy picture. TEK-KOL and the commercial LFC™ plant development team are actively pursuing these opportunities.

FUTURE WORK

The next step in the Project is to continue to deliver high quality, pure PDF™ to utility customers and potential steel industry and ferroally users for test burns. These deliveries will aid in the development of future PDF™ markets and help secure product contracts for commercial LFC™ plants. Work on installing PDF™ finishing equipment, plant capacity upgrades, and CDL™ solids removal systems are expected in 1997. Installation and operation of these systems will provide the operation data and experience important for the final design and construction of a commercial

LFC™ facility.

The goal is to maintain better than 90% availability on the plant this year and complete any remaining major plant modifications by the end of 1997. Efforts to commercialize the LFC™ Technology will continue both at home and abroad. The evaluation of CDL™ upgrading will also continue and a decision made about proceeding with an ENCOAL® plant modification.

CONCLUSIONS

The ENCOAL® Project has completed most of its goals. Essentially all the major Cooperative Agreement Milestones have been met, and final reporting requirements will be completed in early 1997. The debugging phase is complete and steady state operation has been achieved. The LFC™ Technology is essentially demonstrated and marketable PDF™ and CDL™ are being produced.

Significant quantities of both products have been shipped and successfully used by customers, thus proving them to be acceptable fuel sources in today's markets. Efforts to commercialize the LFC™ Technology, both domestically and internationally, are in progress.

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GLOSSARY

AEP	American Electric Power
AS	American Society of Testing Methods
°API	American Petroleum Institute measure of oil density
BACT	Best Available Control Technology
Btu	British Thermal Unit
Center	TEK-KOL Development Center in Perrysburg, Ohio
CDL™	Coal Derived Liquid
CO	Carbon Monoxide
CH_4	Methane
DOE	U. S. Department of Energy
ENCOAL®	ENCOAL® Corporation, a wholly owned subsidiary of Bluegrass Coal Development Co., which is a wholly owned subsidiary of Zeigler Coal Holding Co.
EPA	U.S. Environmental Protection Agency
ESP	Electrostatic Precipitators
IKEC	Indiana-Kentucky Electric Cooperative
lb.	Pound
LFC™	Liquid From Coal
MHI	Mitsubishi Heavy Industries, Hiroshima, Japan
MMBtu	Million British Thermal Units
MOCI	Ministry of Coal Industry
MT	Metric Tonnes
N/A	Not Available
NO_x	Nitrogen Oxides
OPPD	Omaha Public Power District, Omaha, Nebraska
OSHA	Occupational Safety & Health Administration
PDF™	Process Derived Fuel
PRB	Powder River Basin
ROM	Run-of-mine
S-Belt	Vertical conveyor with flexible sidewalls and rubber buckets
SGI	SGI International, LaJolla, CA
SMC	SMC Mining Company, Evansville, IN *(name changed to Bluegrass Coal Development Co.)*
SO_2	Sulfur Dioxide
SPU	Sample Production Unit, TEK-KOL Development Center
Std. Dev.	Standard Deviation
TEK-KOL	A general partnership between SGI International and a subsidiary of Zeigler Coal Holding Company
TGA	Thermogravimetric analysis, procedure for analyzing coal and PDF™
TPD	Tons Per Day
vs.	Versus
WP&L	Wisconsin Power and Light
wt.	Weight
#	Pound